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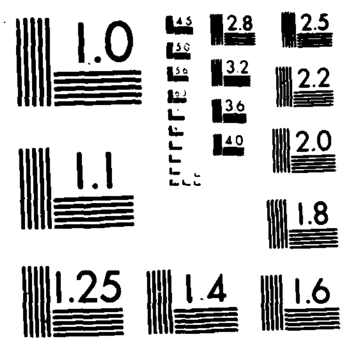

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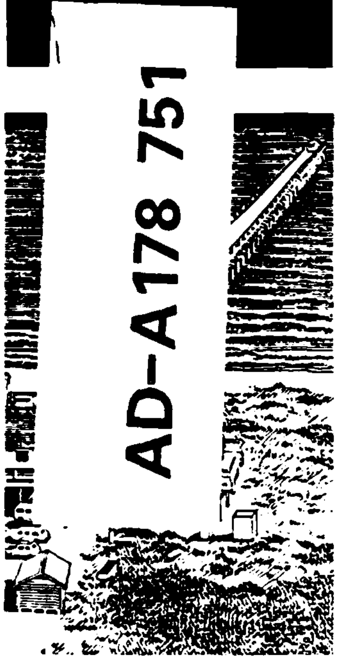

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A WIND- AND WAVE-DRIVEN NEARSHORE CURRENT MODEL

The One-Dimensional Model

by

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A model to calculate the longshore component of currents resulting from winds and waves is described. The model is one-dimensional in the sense that it calculates variables at a number of grid points along a line normal to shore. The user of the model must supply the depth at each grid point along the line; a wave height, period, and mean direction at the seaward end of the line; and the wind speed and direction. The model then calculates the steady-state free surface elevation, longshore and cross-shore current, and wave height and direction at each grid point. Input parameters are described, and a sample application is provided. The model is intended for use where a quick but accurate estimate of the longshore current at an unobstructed, relatively straight shoreline is needed. For more complicated coastal configurations, a two-dimensional model is recommended.

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PREFACE

The research summarized in this report was authorized by the Office, Chief of Engineers (OCE), US Army Corps of Engineers, under the Civil Works Harbor Entrances and Coastal Channels Research Program, "Nearshore Waves and Currents," Work Unit 31672. Funds were provided through the Coastal Engineering Research Area under field management of the US Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) and Mr. John H. Lockhart, OCE Technical Monitor.

This report was prepared by Dr. Jon M. Hubertz, Coastal Oceanography Branch (COB), Research Division (RD), CERC. The study was conducted by personnel of RD under direct supervision of Dr. Edward F. Thompson, Chief, COB, and Mr. H. Lee Butler, Chief, RD; and under general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively. Dr. Charles L. Vincent is CERC Program Manager. This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, CE, was Commander and Director of WES during publication of this report. Dr. Robert W. Whalin was Technical Director.

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A WIND- AND WAVE-DRIVEN NEARSHORE CURRENT MODEL

The One-Dimensional Model

PART I: INTRODUCTION

Background

1. Solutions of coastal engineering problems almost always require a knowledge of mean nearshore waves and currents. Mean currents induced by wave and wind stresses in shallow water provide, in many instances, the major mechanism for the transport of sediment, pollutants, and other constituents in shallow coastal waters. Littoral transport at a site is directly related to longshore and cross-shore currents in the vicinity. Thus, all those problems which require a knowledge of the littoral transport will be more easily solved if the nearshore currents can be predicted. The model discussed in this report introduces a different approach from that recommended in the Shore Protection Manual (SPM) (1984) for the estimation of longshore currents at a coastal site.

2. The SPM presents an equation (Equation 4-20, page 4-54) for calculation of time-mean longshore current generated solely from the breaking of monochromatic waves. The calculated value applies at the breaker position. To calculate longshore currents with this formula, it is necessary to know the beach slope, breaker height, breaker depth, a mixing coefficient, a friction coefficient, and the angle between breaker crest and shoreline. Comparison of longshore speeds calculated with this formula and those measured in the field and laboratory indicates that the formula underpredicts the measured values by a factor of 2.3. Thus, the formula is multiplied by 2.3 to result in a formula for longshore current speed characteristic of the zone between breaker position and shore where the measurements were taken.

3. There are a number of inadequacies in this approach. Waves approaching a shoreline do not all break at the same position since all the waves are not the same height and period. Thus, there are a number of breaker positions, and hence, breaker depths and possibly different bottom slopes at these positions. Not all waves approach the shore from the same angle. There is a spread in wave direction just as there is a spread in wave frequencies.

These objections are removed in the present model by assuming a spectral approach in describing nearshore wave conditions. Thus, it is possible for waves of different heights, periods, and directions to contribute to the generation of longshore currents.

4. The SPM method also assumes that the longshore flow results solely from breaking waves. Measurements at the US Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) Field Research Facility (FRF) show that the wind as well as breaking waves can be an important factor in generating longshore currents (Hubertz 1986). Data from the FRF indicate that the magnitude of the wind-driven component of longshore current is directly proportional to the longshore component of wind speed. The assumption is that steady conditions exist (i.e., the wind blows from a constant direction and at a constant speed long enough for an equilibrium to exist between the wind stress on the water's surface and the bottom stress exerted by the movement of water over the seabed). The time to reach a steady state depends on the wind speed and water depth. For low wind speeds and deep water it will take longer to bring the wind and water into equilibrium than for higher speeds and shallow water. Typically, this time ranges from 1 to 10 hr. It is also important to know where the wind is measured in both horizontal and vertical directions since both the speed and direction can change at a coastal site as the wind moves from overwater to overland and vice versa. This can be important since the wind stress which gives rise to movement of the water is proportional to the wind speed squared. The response of nearshore currents to nearshore winds is being defined more quantitatively in ongoing studies at the FRF.

Scope

5. The effect of the wind is included in the one-dimensional (1-D) wind- and wave-driven nearshore current model discussed in this report. Estimates of longshore current resulting from the wind or waves alone, or both, may be made using this model. Currents can be estimated using either irregular (a spectrum) or regular (monochromatic) waves.

6. The model is formulated assuming the most important processes contributing to nearshore currents are the wind and waves. It is further assumed that these driving forces are balanced by the slope of the sea surface and

bottom friction and that there is no variation of properties in the shore-parallel direction. It is a time-dependent model in the sense that successive steady-state solutions can be computed for time varying inputs. Thus, it can be used to estimate a time series of longshore currents if a time series of wind and/or wave conditions is available as input. If a time variable input is unavailable, the model will calculate a steady-state solution to a constant input of wind and/or wave conditions.

7. The model, which is designed to accept the wind and wave results generated by the Wave Information Study (WIS), can be run on a personal computer thereby reducing computational costs of multiple runs, an example of which would be calculating the nearshore current climatology at a site. A two-dimensional (2-D) model (described in a subsequent report) allows calculation of the 2-D horizontal nearshore circulation for more complex situations but at a higher computational cost. It is felt that the 1-D version will provide sufficiently accurate estimates of the longshore currents for many simple coastal configurations and be an improvement over techniques described in the SPM.

PART II: MODEL DESCRIPTION

Theory

8. The wind- and wave-driven 1-D current model is based on a version of the WES Implicit Flooding Model (WIFM) (Butler 1980), CURRENT, which includes the radiation stress terms (Vemulakonda 1984). The present version has been simplified by excluding advective and lateral shear stress terms and flooding and barrier calculations. Equations used in the model are

$$\frac{\partial u}{\partial t} + g\frac{\partial \eta}{\partial x} + \frac{1}{\rho d}\left(\tau_{bx} + \frac{\partial S_{xx}}{\partial x} - \tau_{sx}\right) = 0 \tag{1}$$

$$\frac{\partial v}{\partial t} + \frac{1}{\rho d}\left(\tau_{by} + \frac{\partial S_{xy}}{\partial x} - \tau_{sy}\right) = 0 \tag{2}$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}(ud) = 0 \tag{3}$$

where

u, v = depth-averaged time-mean horizontal velocity components in the x-, y-directions, respectively (m/sec)

t = time (sec)

g = acceleration of gravity (9.8 m/sec^2)

η = displacement of the free surface with respect to still-water level (m)

ρ = density of the fluid (1,025.0 kg/m^3)

d = total water depth (m), $d = \eta - h$

h = bed elevation with land cells positive and water cells negative (m)

$\tau_{bx,y}$ = bottom stress in the x-, y-directions, respectively (kg/m-sec^2)

$S_{xx,xy}$ = radiation stress in the x-, y-directions, respectively (kg/m-sec^2)

$\tau_{sx,y}$ = surface stress in the x-, y-directions, respectively (kg/m-sec^2)

The coordinate system is shown in Figure 1.

9. The terms $\partial u/\partial t$ and $\partial v/\partial t$ represent the time rate of change of the u, v components of fluid velocity. If the input to the model is

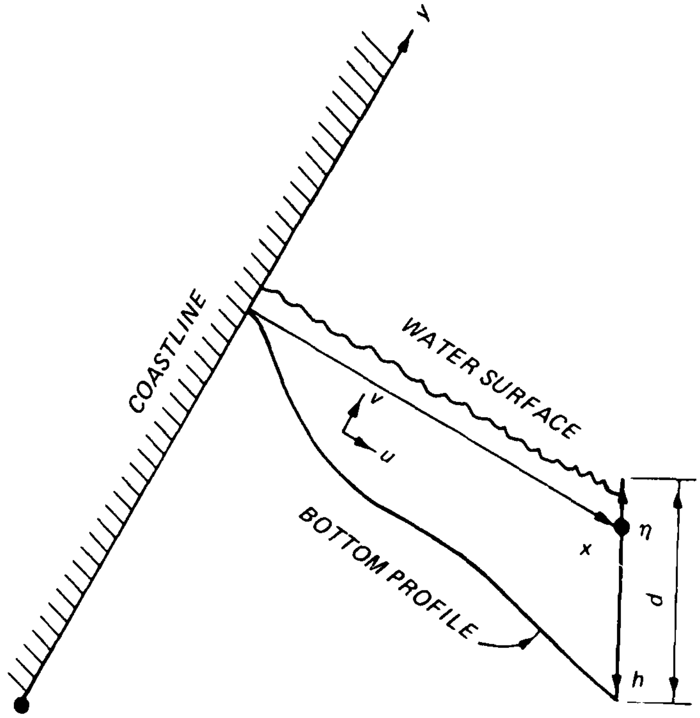

Figure 1. Model coordinate system

constant in time, a steady state will eventually be reached, and these terms will approach zero. The term $g(\partial\eta/\partial x)$ represents the slope of the free surface in the cross-shore direction. Since all parameters are assumed uniform in the alongshore direction, there is no change in η in that direction; therefore the similar term in the equation for v , $g(\partial\eta/\partial y)$, is zero. The terms in parentheses represent the forces per unit volume which accelerate and decelerate the fluid. The terms τ_s and $\partial S_x/\partial x$ are, respectively, surface and radiation stresses resulting from wind and waves. These stresses, or forces per unit area acting on a plane whose unit normal is in the x-direction (Figure 2), can have components in either the x- or y-direction. In Figure 2, the wind is blowing on the water's surface to force the water to flow in the positive x-, y-directions. The waves are propagating toward shore and breaking to force the water to flow in the negative x-, y-directions as indicated by the vectors u, v . Bottom friction is acting against the combined wind- and wave-induced flow indicated in the positive x-, y-directions to retard the flow. The term $\partial\eta/\partial t$ represents the time rate of change of the free surface. Just as $\partial u/\partial t$ and $\partial v/\partial t$, it approaches zero for steady-state conditions. The term $\partial/\partial x(ud)$ represents the flux in the x-direction needed to balance

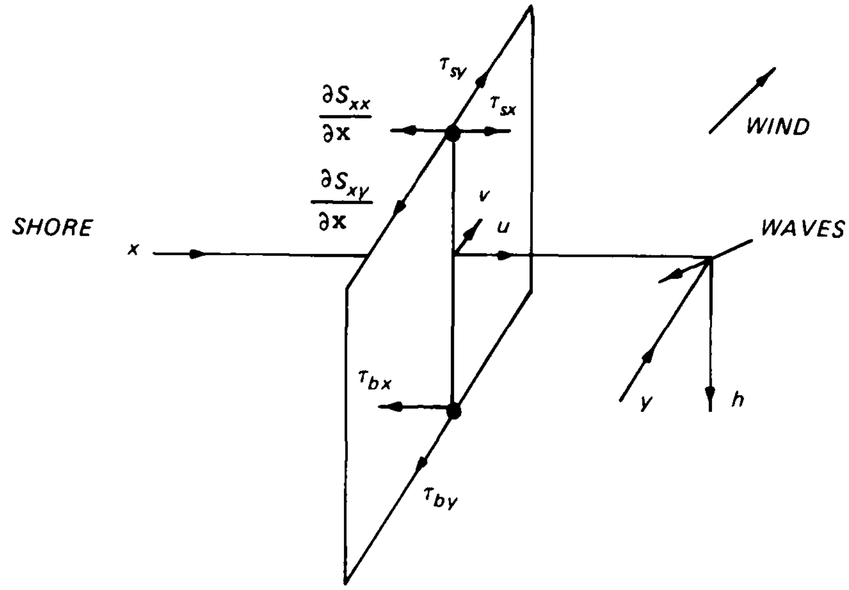

Figure 2. Schematic of stresses acting on a plane

the time rate of change of the free surface. The model is simply a mechanism to adjust u, v, η according physical laws balancing the stresses on the fluid.

Bottom stresses

10. The terms τ_b, τ_s, and $\partial S_x/\partial x$ are all stresses and, by definition, equivalent to a flow of momentum. These terms are discussed next to show their dependence on the bottom, wind, and wave conditions, respectively. The bottom stress term τ_b is usually expressed as

$$\tau_{bx,y} = \rho C_b \left(u^2 + v^2\right)^{1/2} u, v \tag{4}$$

for the x, y components where C_b is an empirically determined nondimensional bottom stress coefficient which depends on the properties of the fluid, depth, and roughness of the bottom. Sometimes C_b is expressed in terms of the Chezy coefficient C

$$C_b = \frac{2g}{C^2}$$

or the Manning's n coefficient

$$C_b = 0.9\ gn^2h^{1/3}$$

The wind- and wave-driven nearshore current model uses Equation 4 to determine the value of the bottom stress. The magnitude of C_b, which normally ranges from 0.001 to 0.01 in coastal areas, is determined from hydraulic experiments involving steady, uniform flow.

11. In the nearshore zone, there is additional fluid motion over the bottom because of gravity waves. This motion can be described as ellipsoidal throughout the water column for linear waves and as a back-and-forth flow at the bottom in the direction of wave propagation. Generally, the magnitude of the wave-orbital flow at the bottom will be larger than the nonwave flow. However, the wave-orbital flow will be near normal to the shore since waves generally propagate near normal to the shore before breaking. Thus, the frictional retardation of the wave-orbital flow relative to the bottom will be greatest in the onshore and offshore directions (i.e., the $\pm\tau_{bx}$ component). The way in which the bottom interacts with combined wave- and nonwave-induced flows to retard the time-mean nearshore flow is unclear. However, FRF personnel are performing measurements to help provide answers to this question. Meanwhile, Equation 4 is assumed to describe the effect of bottom friction on the time-mean flow for both wave- and nonwave-induced flows until research provides improvement.

Surface stresses

12. The surface stress term τ_s represents the force per unit area that the wind exerts on the fluid surface forcing it to move. It has the same form as the bottom stress term and is expressed as

$$\tau_{sxy} = \rho C_s W^2_{x,y} \tag{5}$$

where C_s is an empirically determined nondimensional wind stress coefficient, and W is the wind speed (time averaged for more than 2 min) at an elevation of 10 m. Van Dorn (1953) determined that the coefficient is the result of two effects: one is the frictional drag on the fluid surface which is always present and the other is a form drag because of the presence of waves. These effects are expressed by Amorocho and DeVries (1980) as

$$C_s = C_1 \text{ for } W < W_c$$

$$C_s = C_2 \text{ for } W > W_c \tag{6}$$

$$C_s = C_1 + 0.3(W - W_c) \text{ for } 7 < W < 10$$

where W_c = 7m/sec is a critical wind speed above which the form drag becomes important and C_1 , C_2 are 1.6×10^{-6} and 2.5×10^{-6} , respectively. The original measurements of Van Dorn (1953) were made in a long, narrow, shallow (240 by 60 by 2 m) enclosed basin which is, of course, different from an open coastal site with deeper water. More recent studies (Melville 1977 and Garratt 1977) have confirmed the dependence of the wind stress on the wind speed and sea state for coastal regions and noted that variability in the value of a drag coefficient of 20 to 30 percent is not unusual.

Radiation stresses

13. The radiation stress terms $\partial S_{xx}/\partial x$ and $\partial S_{xy}/\partial x$ represent the flow of momentum in the x-, y-directions, respectively, from the presence of waves and their variation in the x-direction. If wave conditions were allowed to vary in the y-direction (which in this 1-D model they are not) there would be two more components $\partial S_{yy}/\partial y$ and $\partial S_{yx}/\partial y$. A discussion of the physical aspects of radiation stress and derivation of the terms is given in Longuet-Higgins and Stewart (1964). The theory of radiation stress provides a simple and acceptable mechanism for the generation of nearshore wave-driven currents. If assumptions are made consistent with the linear small amplitude theory, the radiation stress components S_{xx} , S_{xy} can be approximated in terms of wave height, direction, frequency, and water depth with the relations

$$S_{xx} = \int_f \int_\theta \left[n \cos^2 \theta + \left(n - \frac{1}{2}\right)\right] E(f,\theta)\, d\theta df \tag{7}$$

$$S_{xy} = \int_f \int_\theta (n \sin \theta \cos \theta)\, E(f,\theta)\, d\theta df \tag{8}$$

where

f = wave frequency (sec^{-1})

θ = wave direction (degrees)

n = the ratio of wave group speed to wave phase speed

E = wave energy per unit area (kgm/sec^2)

where, in practice, the integrals are replaced by summations of the integrands over frequency and direction bands, and $E(f,\theta)$ is the wave spectrum as a function of position. These terms can be estimated as long as the wave spectrum--or wave height, frequency, and direction in the monochromatic case--is known at each grid point. In the 1-D model, the necessary wave information is calculated using a directional-spectral wave transformation model. Given wave information on the ocean boundary, the wave model transforms the wave parameters along the depth profile normal to shore accounting for refraction, shoaling, and wave energy dissipation. The wave transformation model is described in more detail in Appendix A.

14. The equations and terms described above are applied on a finite difference grid with cells that are uniform in size. It is desirable to have sufficient resolution near shore to define the wave decay within the breaker zone. The cell size along the whole profile will be determined by the cell size in the breaker zone. If the profile extends far offshore, the uniform grid will result in more cells and higher resolution offshore than is necessary. For the 1-D model this occurrence is generally not a problem, especially since the model uses an implicit solution technique which allows a longer time-step than an explicit technique. The use of this technique is important for small grid cells since the explicit time-step is limited for the 1-D case by

$$\Delta t \le \frac{\Delta x}{\sqrt{(g\bar{h})}} \tag{9}$$

where

Δt = time-step (sec)

Δx = space-step in the finite difference approximation (m)

g = gravitational acceleration (m/sec^2)

$\bar{h}$ = mean depth (m)

In this implicit model, time-steps can be used a number of times larger than the explicit time-step.

Structure

15. The computer code consists of a main program called Nearshore Current Model One-Dimensional (NSCM1D) and the following four subroutines which are called from the main program:

a. Subroutine DATAIN reads in data files, sets constants, calculates parameters, and initializes variables.

b. Subroutine WAVES transforms input wave conditions from the ocean boundary to shore and calculates the components of radiation stress for use in subroutine MOTION.

c. Subroutine MOTION solves the equations of motion and continuity (Equations 1, 2, and 3) using an alternating direction implicit solution technique to determine wave- and/or wind-driven currents.

d. Subroutine GRIDOUT prints variables out in a matrix corresponding to grid point locations.

The main program controls the time-stepping of the model, updates the variables in time, and controls input and output.

16. Input to the model consists of a 64-character title which identifies the particular application of the model. A system routine on a VAX 750 computer is used to supply the date and time of the model run, so this does not need to be input. Next, a namelist is used to supply the following parameters:

IWAVES - an option parameter of 1 or 0 which determines, respectively, whether wave data will or will not be used

WINDSPD - the wind speed in metres per second (if no wind forcing is desired, set equal to 0)

WINDDIR - the direction in degrees from which the wind is blowing, 0 deg from the north, 90 deg from the east, etc.

ROTA - the orientation in degrees of the negative x-axis of the model if it points toward WEST, ROTA = 0 deg, toward SOUTH, ROTA = 90 deg, etc.

MMAX - the number of grid cells normal to shore

TIDELEV - the level of the water in metres with respect to mean sea level during the model applications

NPRINT - the number of time-steps between the printout of results

TAU - time-step in seconds

DX - grid cell size in metres in the x-direction

DADJ - bed elevation datum adjustment in metres

SMAX - a value of surface elevation that, if exceeded, indicates abnormal results

MAXTIM - simulation will stop after MAXTIM time-steps

BFC - the value of the bottom friction coefficient

Following the namelist, the bed elevations (in metres) along the shore-normal line are read in. Note that the first value read in should be positive to represent land above sea level and large enough so that the water level will never exceed the land elevation. If wave-driven currents are desired, subroutine WAVES is called next and the necessary wave data read in.

17. There are three options to specify the input wave spectrum. The first option requires specifying the wave height HMO (metres) the peak period TP (seconds) and the mean direction THETB (degrees from shore-normal; see Figure 3). The model will construct a parameterized spectrum

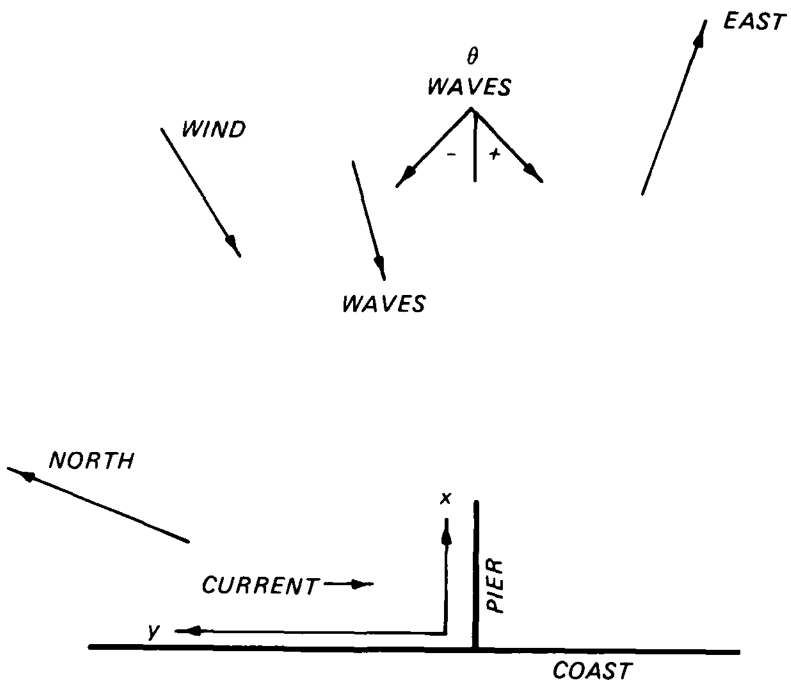

Figure 3. Schematic of forces acting nearshore

using these three parameters and the water depth. This spectrum will be single peaked and representative of a wind-sea spectrum in shallow water. The theory used to construct this spectrum is described by Hughes (1984). The second option uses this same theory but allows the adjustment of some of the parameters determining the shape of the spectrum which is still required to be single peaked; however, the shape can be varied to fit some desired form.

Model input for this option consists of peak frequency FM (hertz), alpha ALPHA (Phillip's nondimensional equilibrium constant), gamma GAMMA (a nondimensional spectral peakedness parameter), sigma a and b SIGMAA and SIGMAB (nondimensional spectral width parameters), respectively, and the mean direction THETB (degrees). The third option allows the input spectrum to be specified directly. For example, if a spectrum were measured at an offshore point, it could be input to the model at the ocean boundary in terms of spectral energy (m^2 sec) in a number of frequency and direction bands.

18. The input parameters which control the operation of subroutine waves are given in a namelist form as follows:

ITYPE2 - option to read in wave parameters and have the model construct a spectrum = 1, or option to read in spectral shape parameters and have the model construct a spectrum = 2, or option to read in a spectrum = 3

IPRINT - option to suppress (= 0) or (= 1) printout of the 2-D spectrum at each grid point

NFRC - number of discrete frequency bands

NANG - number of discrete directional bands

IFRD - option to either internally compute frequency bands = 0 given the starting frequency FFO and the frequency interval DFF or read in frequency bands = 1

NN - the exponent of the cosine spreading function

The final input after this namelist depends on the value of the parameter ITYPE2 . If ITYPE2 = 1 , H_{mo} , the period at the peak of the spectrum, and the mean direction are read in an F6.1 format. If ITYPE2 = 2 , the peak frequency, alpha, gamma, sigma a, sigma b and the mean direction are read in the format (2F6.4, F6.1, 2F6.2, F6.1). If ITYPE2 = 3 , the mean direction is read in format F6.1 and then spectral energy values (m^2 sec) at each frequency are read in format 10F6.2. An example of an input data set is given in Part III.

19. The model output consists of a summary of the input data and options chosen and the computed values of wave height, surface elevation, and longshore current velocity at times specified. These values are provided at each grid point on the profile line normal to shore. A test case is presented next to illustrate model input and output.

PART III: MODEL APPLICATION

20. A typical use of the 1-D model might be to estimate the longshore current profile at a coastal site characterized by various combinations of wind and waves. The first task in applying the model is to assemble the site-specific data needed for input. These data consist of the bathymetry profile normal to shore from the site to some depth beyond the region of interest, the wind speed and direction over the region, and the wave height, period, and direction at the seaward boundary.

Bathymetric Data

21. The bathymetry should be in metres and negative if below mean sea level. In many cases, the bathymetric data will not be coincident in time with wave and wind data and may, in fact, consist of observations made over a number of years. Bathymetric contours can change significantly in shallow water, especially after storms. Consequently, a bathymetry profile that is most representative of the site should be used. If historical data are available, the model can be run with various bathymetry profiles representative of the range of profile variations.

Wind Speed and Direction Data

22. The wind speed and direction should be representative of the regions of interest. If the only wind data available are miles away from the site, an attempt should be made to estimate from large-scale weather maps the homogeneity of the wind field between the wind measurement point and the site of interest. Also, the site should be examined to determine if there are any local topographic features which might influence the wind speed and direction over the region of interest. The wind speed should be specified in metres per second as a mean value over 10 min and measured at a 10-m elevation. In the SPM, Equation 3-26 (page 3-26) can be used to adjust the wind speed to the 10-m elevation. The direction is specified using the meteorological convention (i.e., a north wind blowing from the north toward the south would have a direction of 0 deg with respect to true north; an east wind would have a direction of 90 deg, etc.). If ideal wind measurements are unavailable, mean

conditions representative of the site should be used. These could probably be obtained from climatological records at the nearest measurement site.

Wave Data

23. Wave data will probably be more scarce than wind data. If no local measurements exist, simulated data or statistical summaries as provided by the WIS should be used (Ragsdale 1983). As a minimum, a mean wave height, period, and direction representative of the time and site of interest should be estimated. The wave height should be in metres, the period in seconds, and the direction in degrees from shore-normal. Facing the sea, waves coming from the left quadrant are indicated by positive angles and waves coming from the right quadrant by negative angles. (See Figure 3 for a schematic description.) The wave height should be the height in the depth of water at the seaward boundary of the bathymetry profile. In the extreme, the wave height will probably not exceed 0.4 to 0.6 times the water depth. This is a spectral energy based estimate. Individual waves may exceed this criterion.

24. It is evident that an ideal input data set will seldom exist for a typical application of the model. The best procedure in this case is to examine what is available and then develop combinations of bathymetry, winds, and waves which seem consistent with mean or typical conditions at the site of interest. Developing a range of conditions such as this allows a concurrent set of longshore current velocity profiles to be simulated with the model. This range could then provide an estimate of mean and/or extreme longshore current conditions at a site. In the case when enough data are available to assemble a wind and wave climatology for a site, an accompanying longshore current climatology can be calculated with the model.

DUCK '85 Data

25. Measurements taken at the FRF in September 1985 as part of the DUCK '85 experiment provide an example of an almost ideal input data set. Using the Coastal Amphibious Research Buggy (CRAB), FRF personnel made bathymetric measurements along a profile line normal to shore. They measured wind speed and direction over unobstructed water (about 500 m from the bathymetric measurements) at an elevation of 19 m at the end of the pier. They also made

directional-spectral wave measurements with a pressure gage array at the seaward end of the profile line and with combinations of pressure gages and current meters located at five positions along the profile line. Thus, there was not only a good input data set but also measured longshore currents available for comparison to model results.

26. On 11 September 1985, the wind and waves were from the northeast resulting in southerly longshore currents. Data from the directional pressure gage array indicate that waves with a significant height of 1.0 m and a significant period of 6.5 sec were propagating toward 239 or 11 deg with respect to shore-normal toward the south. The wind averaged over 40 min and, reduced to a 10-m elevation, was 11 m/sec from 38 deg east of north. These conditions were fairly uniform for about 6 hr. A schematic of conditions is shown in Figure 3. The input data set for this case is as follows:

```
 ONE DIMENSIONAL CURRENT MODEL - 11 SEPT. 85 1800 EST
 &PAR IWAVES=1,WINDSPD=11.0,WINDDIR=38.,ROTA=18.,MMAX=32,
 TIDELEV=0.50,NPRINT=100,TAU=60.,DX=15.,DADJ=0.,SMAX=5.3,MAXTIM=400,
 BFC=0.0020 &END
 5.00 -0.75 -1.10 -1.20 -1.30 -1.50 -2.25 -2.75 -3.00 -3.25 -3.40 -3.50 -3.60
-3.70 -3.80 -3.90 -4.00 -4.10 -4.20 -4.30 -4.40 -4.50 -4.60 -4.70 -4.80 -4.90
-5.00 -5.20 -5.40 -5.6- -5.80 -6.00
 &WAV ITYPE2=1,IPRINT=0,NFRC=14,NANG=36,IFRD=0,NN=4, &END
 0.11000 0.0100
   1.0   6.5  11.0
```

The first line is descriptive text of the case being run. The second through fourth lines constitute namelist PAR which contains various model parameters described previously and summarized below.

IWAVES=1 - include effects of waves in the calculations
WINDSPD=11.0 - wind speed 11 m/sec
WINDDIR=38 - wind direction 38 deg with respect to north
ROTA=18 - x-axis rotated 18 deg south of west
MMAX=32 - 32 grid cells in the shore-normal profile
TIDELEV=0.5 - calculations done at 0.5-m above msl
NPRINT=100 - print out results every 100 time-steps
TAU=60 - time-step 60 sec $\Delta t = 25 \left(\frac{15}{\sqrt{9.8(4)}}\right)$

DX=15 - grid cell size 15 m

DADJ=0 - no adjustment to the datum level

SMAX=5.3 - if elevations exceed 5.3-m abnormal termination

MAXTIM=400 - calculate for 400 time-steps

BFC=0.0020 - value of the bottom friction coefficient for the sandy bottom characteristic of the FRF site

The next three lines contain the depths in metres of the grid cells from the shore to the ocean boundary. The eighth line contains namelist WAV with the following parameters:

ITYPE2=1 - to input wave characteristics and let model calculate spectra

IPRINT=0 - to suppress printing out 2-D spectra at each grid cell

NFRC=14 - 14 frequency bands

NANG=36 - 36 angle bands

IFRD=0 - to compute frequency bands using an initial frequency and an incremental frequency

NN=4 - to use 4 as power of cosine spreading function

The ninth line specifies, respectively, the initial and incremental frequencies for calculating the frequency bands. The last line specifies, respectively, the significant wave height in metres, the significant period in seconds, and the direction of wave propagation measured away from shore-normal. The sign (+ or -) convention for the wave approach angle is shown in Figure 3.

27. The model was run for 400 time-steps with the above input parameters. The longshore current at grid point 16 is shown in Figure 4 as it develops during the simulation. A steady state can be assumed after approximately 300 time-steps. The current changes by only 3 percent between time-step 300 and 400 so that the steady-state criterion of little change in velocity with time could be assumed to be met effectively after 300 time-steps.

28. The calculated and measured values of longshore current and wave height at each of the measurement points along the profile line are shown in Figure 5. The measured bottom profile is shown to relate wave dissipation and longshore wave-induced current to the bottom profile. Wave height increases slightly as the waves shoal on the 0.0066 slope and then starts to decrease as breaking occurs on the 0.028 slope. The longshore current responds by being uniform up to the slope break where the current begins to increase in response

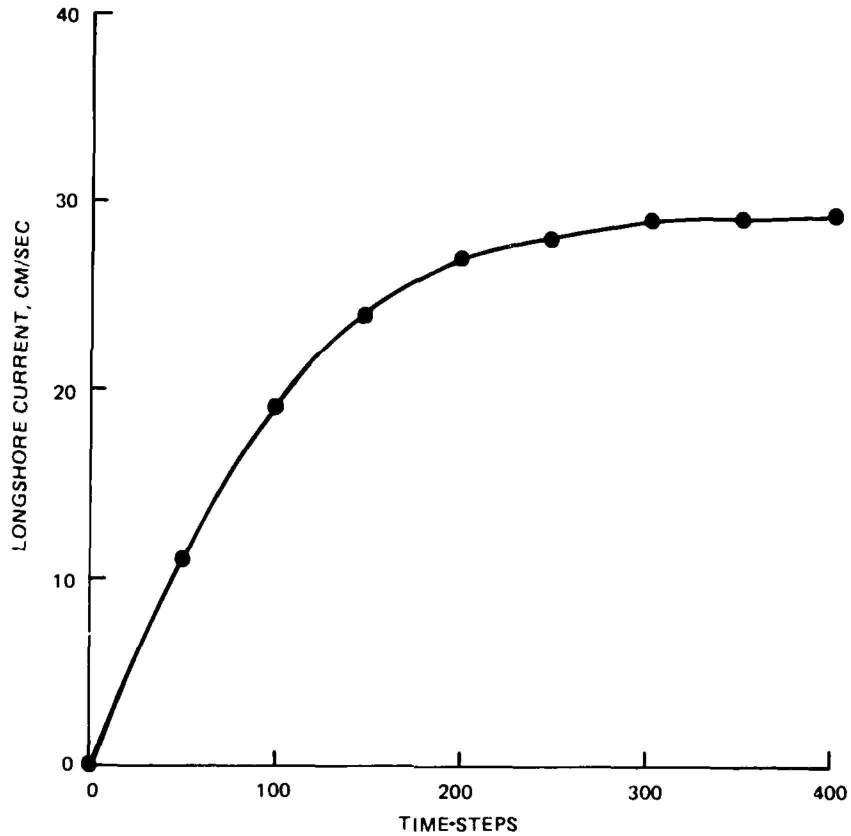

Figure 4. Approach of longshore current to steady state at grid point 16, FRF

to wave dissipation. Unfortunately, wave height and longshore current measurements are not available within the last 60 m between the shoreline and first measurement point to define the wave height and longshore current profile. Seaward of the slope break the longshore current has a rather uniform distribution with a magnitude of about 30 cm/sec. This phenomenon is attributed to the wind-driven component of nearshore flow and is represented by the wind stress term in the model.

29. The model was run for this same case with first the wind set to zero and then the waves set to zero to illustrate the separate contributions of these terms. The longshore current profile from the model for these cases is shown in Figure 6 along with the case when both terms are present. It is obvious from this illustration that one cannot model nearshore currents properly with a model that represents only the wind component or only the wave component; the model needs to have both present.

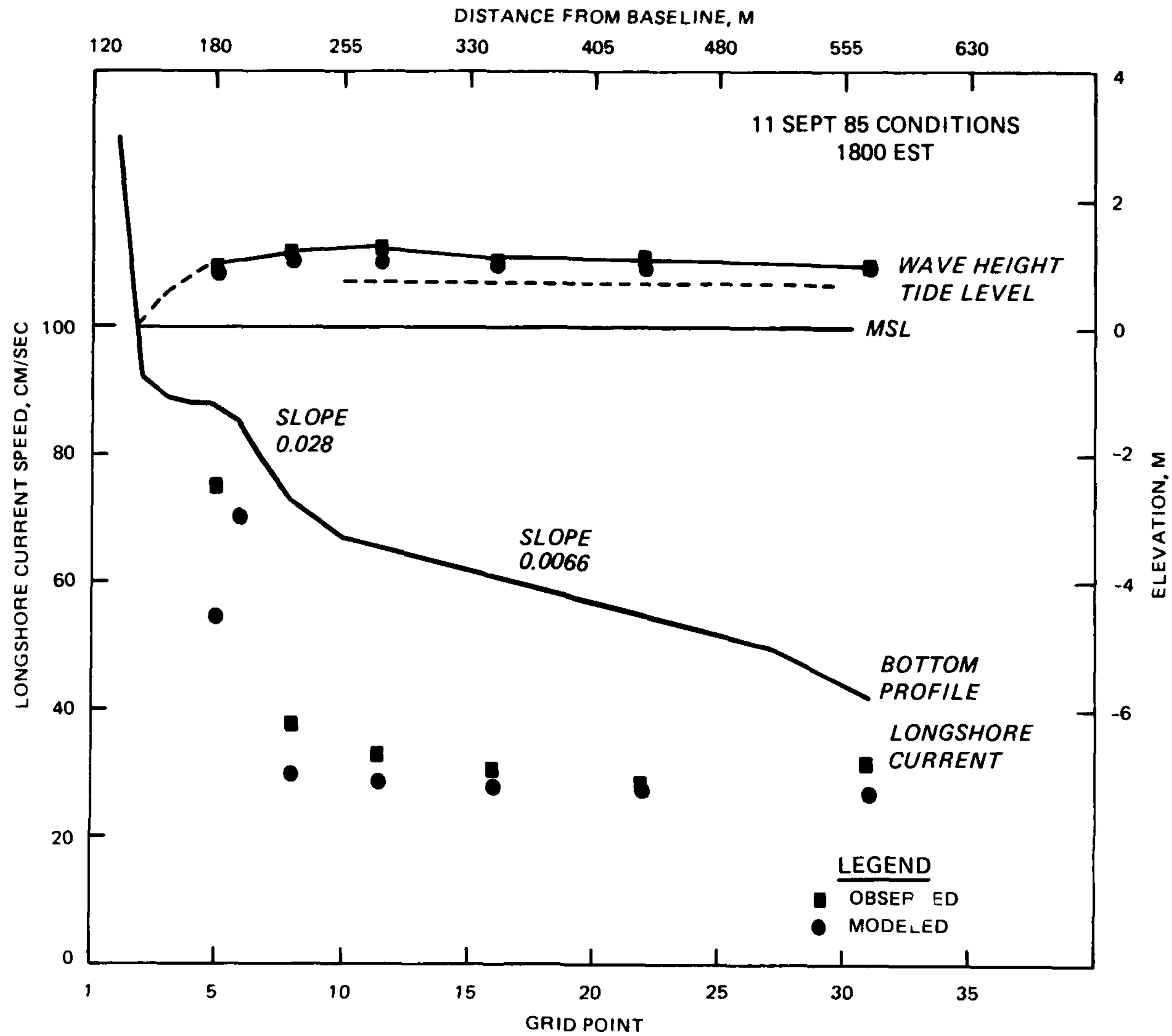

Figure 5. Observations and model results for 11 September 1985 conditions

30. Applying Equation 4-22 in the SPM, the longshore current at the breaker position is 25 cm/sec for $m = 0.028$, $H_b = 1.0$, and $\alpha_b = 4$ deg. The value of α_b was obtained from refracting a wave with an initial angle of 11 deg over the bottom profile in Figure 5 and taking the calculated angle at grid point 5. This assumes the commonly accepted values of the coefficients $\Gamma = 0.2$, $\beta = 1.2$, and $f_f = 0.01$. Any one or all of these coefficients could be adjusted to obtain the observed longshore current value of about 75 cm/sec near the breaker position, but it is not obvious beforehand which values to choose. The present model relies on input of wave height, period, and angle; the bottom profile; and wind speed and direction, all of which are measurable quantities or could be estimated for a coastal site.

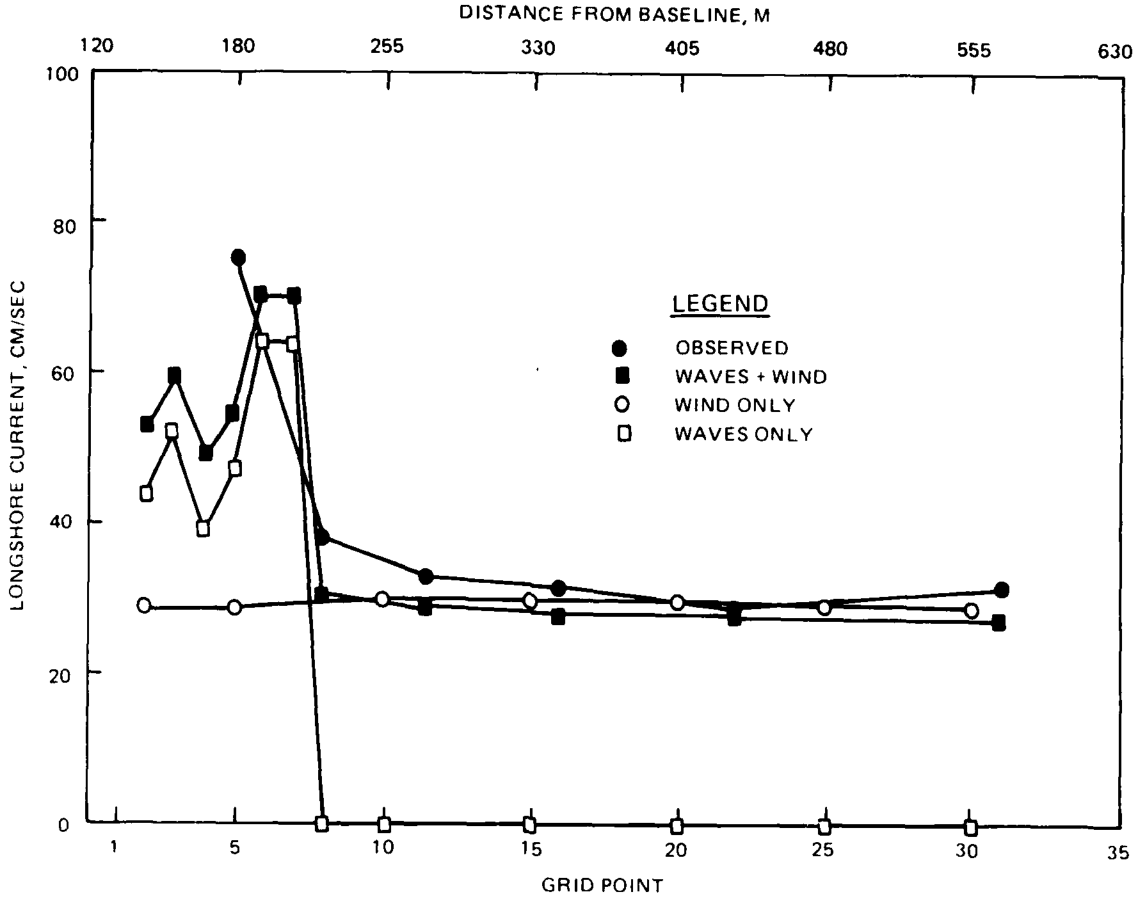

Figure 6. Contribution of wind and wave components at the FRF

31. One other example is presented which represents a high energy situation. This is a hindcast of the waves and currents resulting from Hurricane Gloria which passed offshore of Duck, North Carolina, on 27 September 1985, when the nearshore wave and current instrumentation was still in place. Conditions at 2200 hours EST on 26 September 1985 were: tide level = 0.4 m; wind direction = 90 deg; wind speed = 19 m/sec; wave height at outermost gage = 2.6 m; peak wave period = 15 sec; mean wave direction = -20 deg, with respect to shore-normal. The mean wave direction was estimated from visual observations of 80 deg with respect to North at 0720 hours EST on 26 September and 110 deg with respect to North at 1030 hours EST on 27 September and assuming the waves will be close to the wind direction. These are not steady conditions since they represent an instant in time during the passage of a hurricane. Thus, the assumption that conditions remain steady long enough for the model to come into equilibrium is probably violated. The fact that

conditions are changing can be seen in Figure 7, which shows values of the longshore current at hours 1900 through 2200 EST. There is essentially no variation in wave height during this time, so it can be assumed that wave energy has reached a limiting value in these depths. The longshore current also appears limited since there is little variation nearshore, but at greater depths the current is increasing. The model reproduces the peak of the longshore current but falls too rapidly on either side. This occurrence may result from poor representation of the actual spectral shape and is being studied. Use of Equation 4-22 in the SPM for this situation gives a value of 90 cm/sec for values of H_b = 1.5 m and α_b = 12 deg which again underestimates the longshore current.

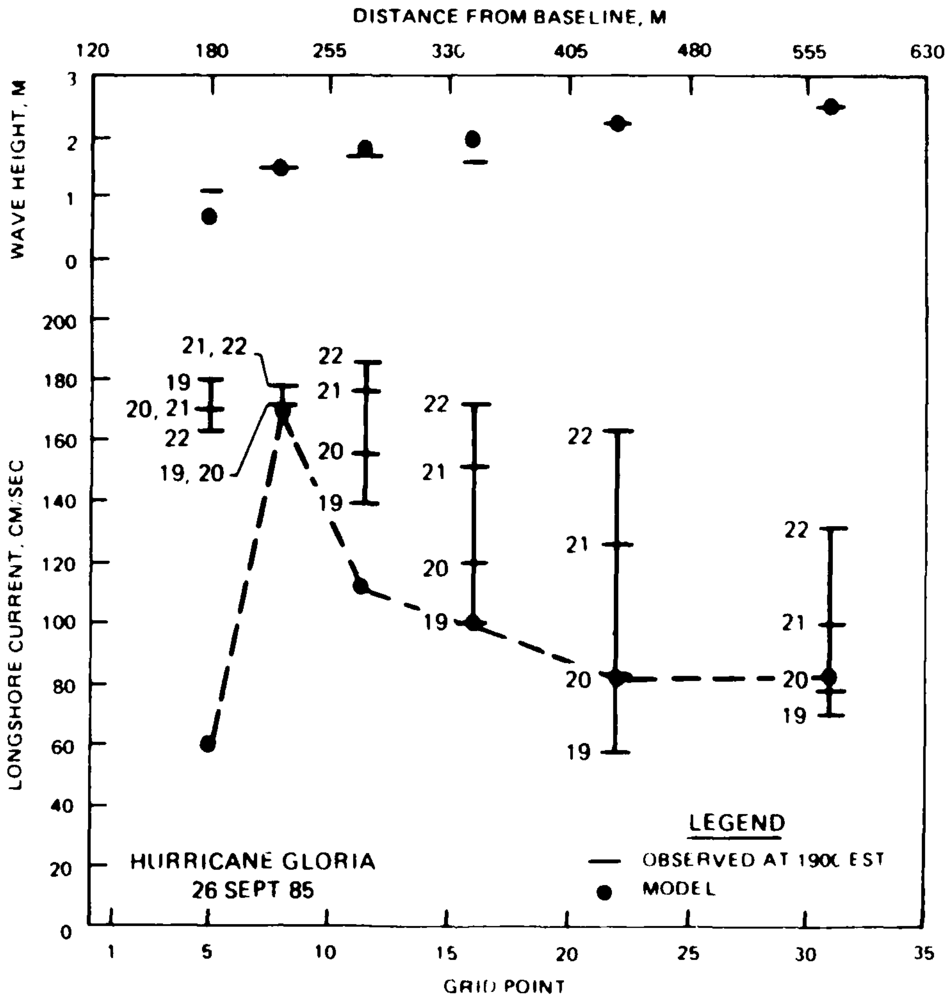

Figure 7. Observations and model results for Hurricane Gloria's condition

PART IV: SUMMARY

32. A simple 1-D model has been described and applied to two situations where good observations of currents, waves, and winds are available for comparison. The model reproduces the magnitude and direction of the longshore current nearshore as well as outside the region of depth-induced wave breaking. Wave heights along the shore-normal profile are also reproduced.

33. For execution, the model requires a profile of depths normal to shore; wave height, period, and mean direction at the seaward boundary of the profile; and the wind speed and direction over the region. From this input, the model calculates a steady-state distribution of longshore current normal to shore. The wave height distribution normal to shore is also calculated as a requirement for determining the current.

34. Evidence indicates that the 1-D wind- and wave-driven nearshore current model offers a more complete and accurate technique for the calculation of longshore currents than that available in the SPM while still retaining a degree of simplicity which makes it easy to use and understand. It is expected that this model will be useful in many engineering and scientific applications which satisfy the assumptions of the model.

REFERENCES

Amorocho, J., and DeVries, J. J. 1980. "A New Evaluation of the Wind Stress Coefficient Over Water Surfaces," Journal of Geophysical Research, Vol 85, pp 433-442.

Bouws, E., et al. 1985. "Similarity of the Wind Wave Spectrum in Finite Depth Water, Part I - Spectral Form," Journal of Geophysical Research, Vol 90, pp 975-986.

Butler, H. L. 1980. "Evolution of a Numerical Model for Simulating Long Period Wave Behavior in Ocean-Estuarine Systems," Estuarine and Wetlands Processes with Emphasis on Modeling, Marine Sciences Series, Vol 11, Plenum Press, N. Y.

Garratt, J. R. 1977. "Review of Drag Coefficients Over Oceans and Continents," Monthly Weather Review, Vol 105, pp 915-929.

Hubertz, J. M. 1986. "Observations of Local Wind Effects on Longshore Currents," Coastal Engineering, Vol 10, pp 275-288.

Hughes, S. A. 1984. "The TMA Shallow-Water Spectrum: Description and Applications," Technical Report CERC-84-7, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Longuet-Higgins, M. S., and Stewart, R. W. 1964. "Radiation Stresses in Water Waves: A Physical Discussion with Application," Deep Sea Research, Vol 11, pp 529-562.

Melville, W. K. 1977. "Wind Stress and Roughness Length Over Breaking Waves," Journal of Physical Oceanography, Vol 7, pp 702-710.

Ragsdale, D. S. 1983. "Sea-State Engineering Analysis System: User's Manual," Wave Information Study Report 10, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Shore Protection Manual. 1984. 4th ed., 2 Vols, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC.

Van Dorn, W. G. 1953. "Wind Stress on an Artificial Pond," Journal of Marine Research, Vol 12, pp 249-276.

Vemulakonda, S. R. 1984. "Erosion Control of Scour During Construction, Report 7, Current - A Wave-Induced Current Model," Technical Report HL-80-3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

APPENDIX A: WAVE TRANSFORMATION MODEL

1. Predicting the transformation of a wave spectrum over shallow water and through the surf zone is of critical importance in estimating the wave-driven component of current in the nearshore region. The dissipation of wave energy as waves approach the shore is the source of energy for the wave-driven component of flow. Thus, being able to specify the location and amount of wave energy dissipation is a prerequisite for calculating currents.

2. The nearshore current model discussed in this report has as one of its components a directional-spectral wave transformation model. Given certain input information this model calculates the wave energy and direction of a spectrum of waves along the profile normal to shore. Using this information, the radiation stress components are calculated and used in the equations of motion to generate wave-driven currents.

3. The theory proposed by Bouws et al. (1985)* and summarized by Hughes (1984) is the basis for the wave transformation model. Hughes (1984) serves as the basis for the following discussion on the TMA shallow-water spectrum.** Given a wave height H_{mo} at depth h, the spectral coefficients α and γ are calculated based on the significant steepness ε.

$$\varepsilon = \frac{H_{mo}}{4L_m}$$

$$\alpha = 16\pi^2\varepsilon^2$$

$$\gamma = 6614\varepsilon^{1.59}$$

where L_m is the wavelength associated with the peak frequency. These coefficients are used to calculate a TMA energy spectrum $E(f,h)$ at the seaward boundary of the shore-normal profile. A cosine spreading function is used to spread the energy about a mean direction. This spectrum is then

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* References cited in the appendix can be found in the References at the end of the main text.

** Field data from three separate studies (Texel, MARSEN, and ARSLOE) on shallow-water wind wave growth were used in the TMA spectral representation.

refracted and shoaled along the profile line assuming straight and parallel contours with the relation

$$E(f, \theta, h) = E_o(f, \theta, h) \frac{C_o C_{go}}{C C_g}$$

where C is the phase velocity, C_g the group velocity, and the subscript "o" refers to the seaward boundary point.

4. Next, the spectrum is examined, frequency by frequency, at each depth proceeding toward shore to determine if the energy at that frequency exceeds the limit imposed by the TMA spectral shape. For the case when $H_{mo} > 0.4h$, the input α and γ remain fixed, and the spectral shape is controlled by the ϕ term which is a limiting factor and a function of frequency and depth. For other cases, α and γ are determined by the local steepness and determine the shape of the spectrum. For all cases $H_{mo} > 0.6h$ the relation

$$\alpha = 3.55 \frac{h}{g} f_m^2$$

is used to limit the energy.

5. This approach gives acceptable results for dissipating wave energy as a function of depth but is limited in that it only considers single peaked spectra. Improvements are being sought as more data become available.

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